
Chapter 7

Detailed Investigations of Raw Materials

Detailed investigations of raw materials

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1. INTRODUCTION

The overall investigations of raw materials have proved that one of the deposits investigated is suitable for the purposes of clinker / cement production. Therefore, the proposed cement plant is feasible. The last step of the investigations, known as detailed investigations of raw materials, is carried out in order to define the selected deposit accurately in quantity and quality. Once these detailed investigations have been completed, it is possible to 'construct' a computer generated block model (CADE) and implement QSO Expert systems for medium and long term planning.

The main tasks in this step are as follows:

- ◆ Detailed drilling campaign in order to obtain the most accurate information with respect to the geological structure, chemical behaviour and associated reserves of the deposit. The drilling volume usually is in the order of between 1000 and 2000 m, whilst 300 to 1000 samples will be selected for chemical analysis.
- ◆ Geotechnical data to assess the overall stability of the slopes, rock strength, fracture patterns, groundwater circulation
- ◆ Quarry layout and development concept is prepared by the mining engineer

2. DETAILED DRILLING CAMPAIGN: OPTIMAL DRILL HOLE PATTERN

A question asked frequently during the exploration stage of a deposit is: "how much drilling is required to accurately describe the deposit and to achieve the required precision of results?"

The normal procedure is to apply geostatistics on the chemical data of the initial drilling campaign. With the help of variograms, which are a measure of the **spatial** interdependence of chemical characteristics between the drill holes, it is possible to determine the optimal drill hole pattern.

Fig 1 is a graphic display of the relationship between possible errors of estimation and number of drill holes, using a statistical and geostatistical approach. Two important conclusions can be derived from this figure:

- ◆ to achieve a required accuracy, the number of drill holes can be reduced significantly using geostatistical methods
- ◆ using geostatistical analyses on the same number of drill holes, the error of estimates is reduced.

Fig. 1 Relationship between number of drill holes n and estimation error using statistics (dashed line) and geostatistics.

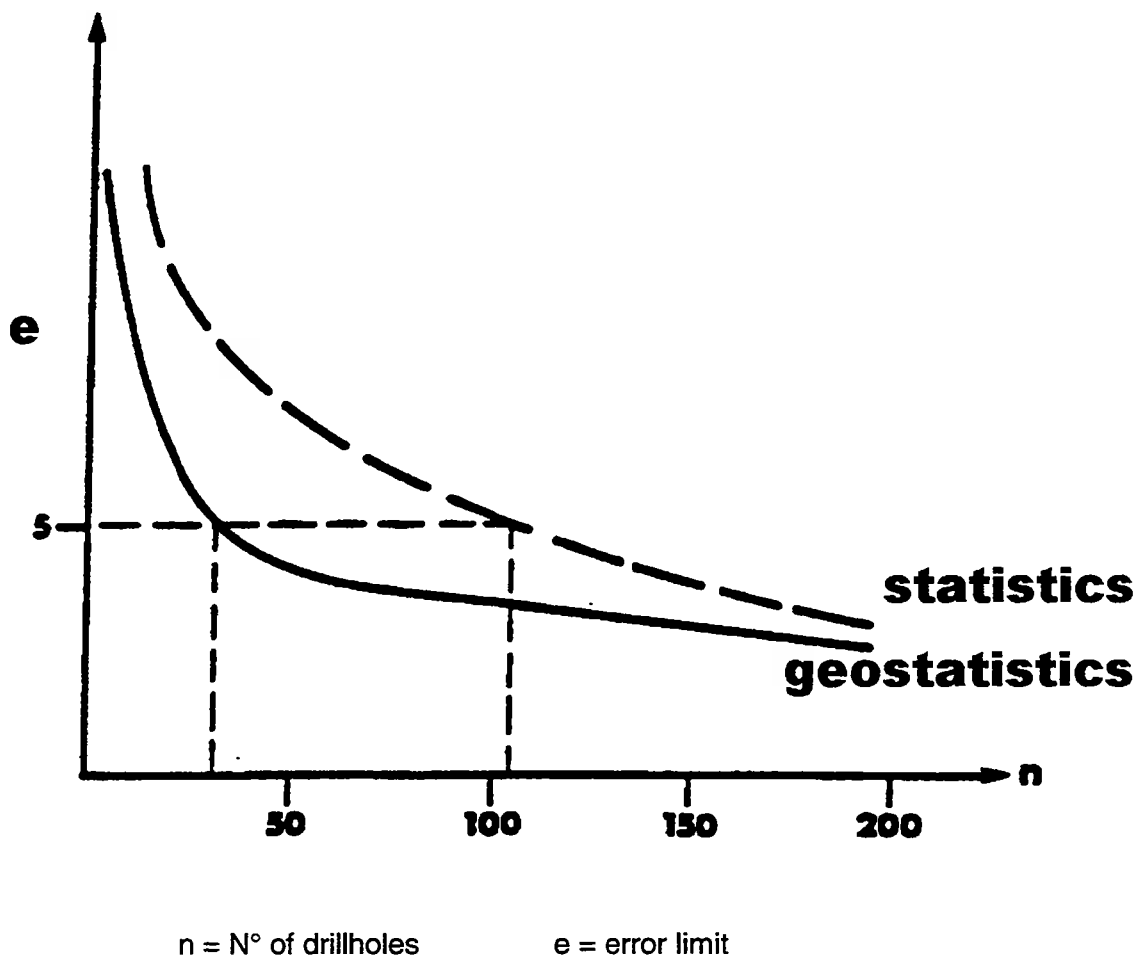
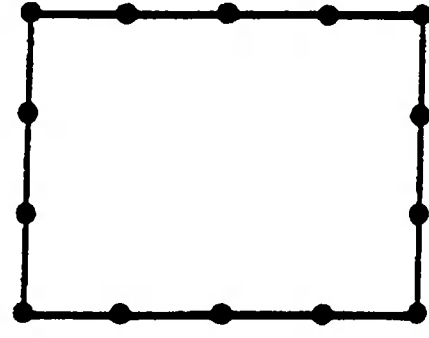
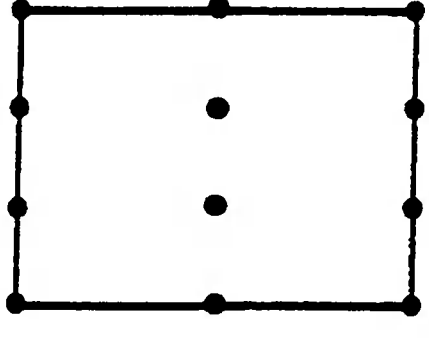
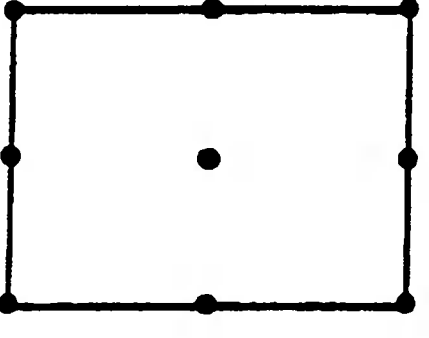
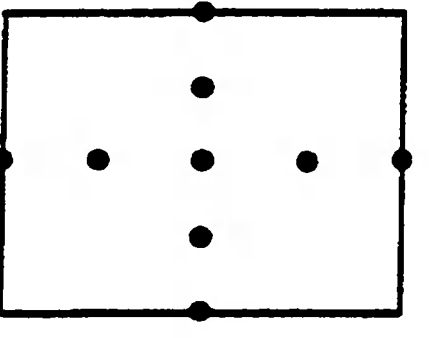


Fig. 2 **Comparison of the errors associated to different sampling patterns.**

	n	σ_k^2
	14	6.65
	12	5.50
	9	4.95
	9	4.60

Optimal grid design (spacing, regular, irregular, etc.) can be tested with the aim to minimise the estimation errors in the interpretation of the data by kriging (Fig. 2)

3. GEOTECHNICAL ASPECTS

In designing the quarry slopes, we are faced with two conflicting requirements. On the one hand by steepening the slope, the stripping ratio waste / ore to be excavated is reduced and recoverable reserves are increased. On the other hand, loss of life and serious damage to property can result from failures induced by excessive steepening of particular slopes. A compromise between steepness and economy has to be found for an economically safe quarry.

A practical solution is built up from the investigations of the following criteria:

- ♦ **Geological data:** lithology (presence of thin intercalations of clay), geological mapping, strike and dip of all types of planes and structures in the deposit
- ♦ **Physical data:** rock strength, cohesion, angle of friction
- ♦ **Groundwater conditions:** the presence of groundwater in the rock mass surrounding an open pit has a detrimental effect upon the mining programme for the following reasons:
 - water pressure reduces the stability of the slopes and increases the forces tending to induce sliding
 - high moisture content in shales decrease the stability

Freezing of groundwater during winter can cause wedging in water-filled fissures due to volume changes in the ice. Freezing of surface water on slopes can block drainage paths resulting in a build-up of water pressure in the slope with a consequent decrease in stability.

Discharge of groundwater into an open pit gives rise to increased operating costs because of: (a) the requirement to pump this water out, (b) also because of the difficulty of operating heavy equipment on very wet ground and (c) increased wear / maintenance of in-pit equipment.

Liquefaction of overburden or waste tips can occur when water pressure within the materials rises to the point where the uplift forces exceed the weight of the soil.

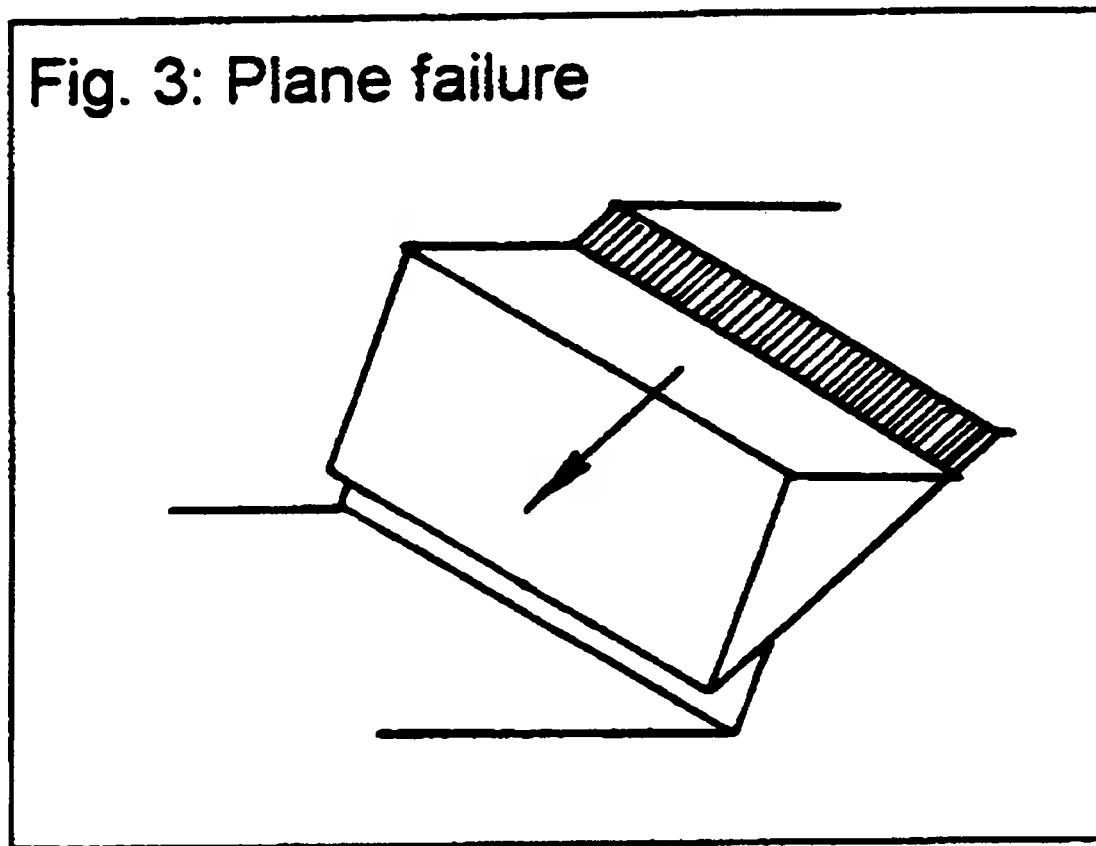
By far the most important effect of the presence of groundwater in a rock mass is the reduction of stability resulting from water pressures within the discontinuities in the rock.

3.1 Slope failures

The following stability problems could be expected in an open pit quarry:

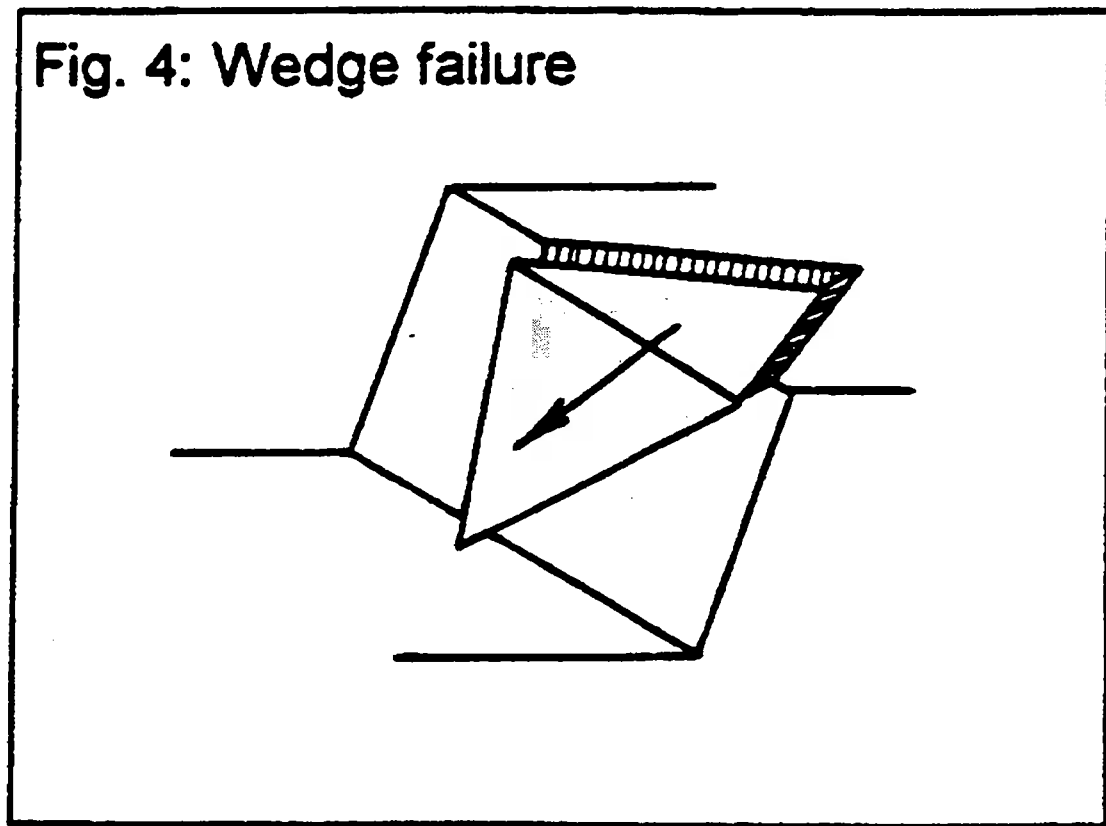
Plane failure occurs when a geological discontinuity, such as a bedding plane, strikes parallel to the slope face and dips into the excavation at an angle greater than the angle of friction.

Fig. 3 Plane Failure



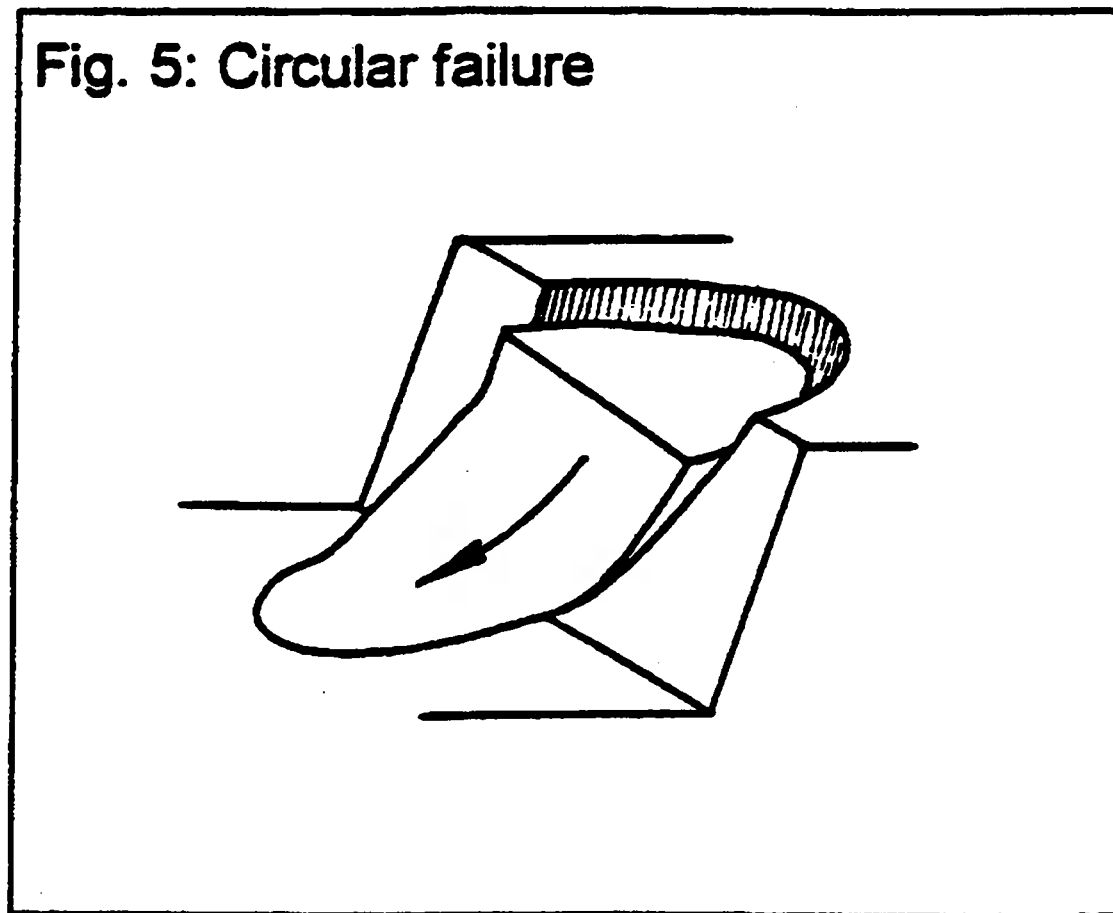
Wedge failure (Fig. 4) occurs when two discontinuities strike obliquely across the slope face and their line of intersection daylights in the slope face. The wedge of rock resting on these discontinuities will slide down along the line of intersection, if the inclination of this line is greater than the angle of friction.

Fig. 4 Wedge Failure



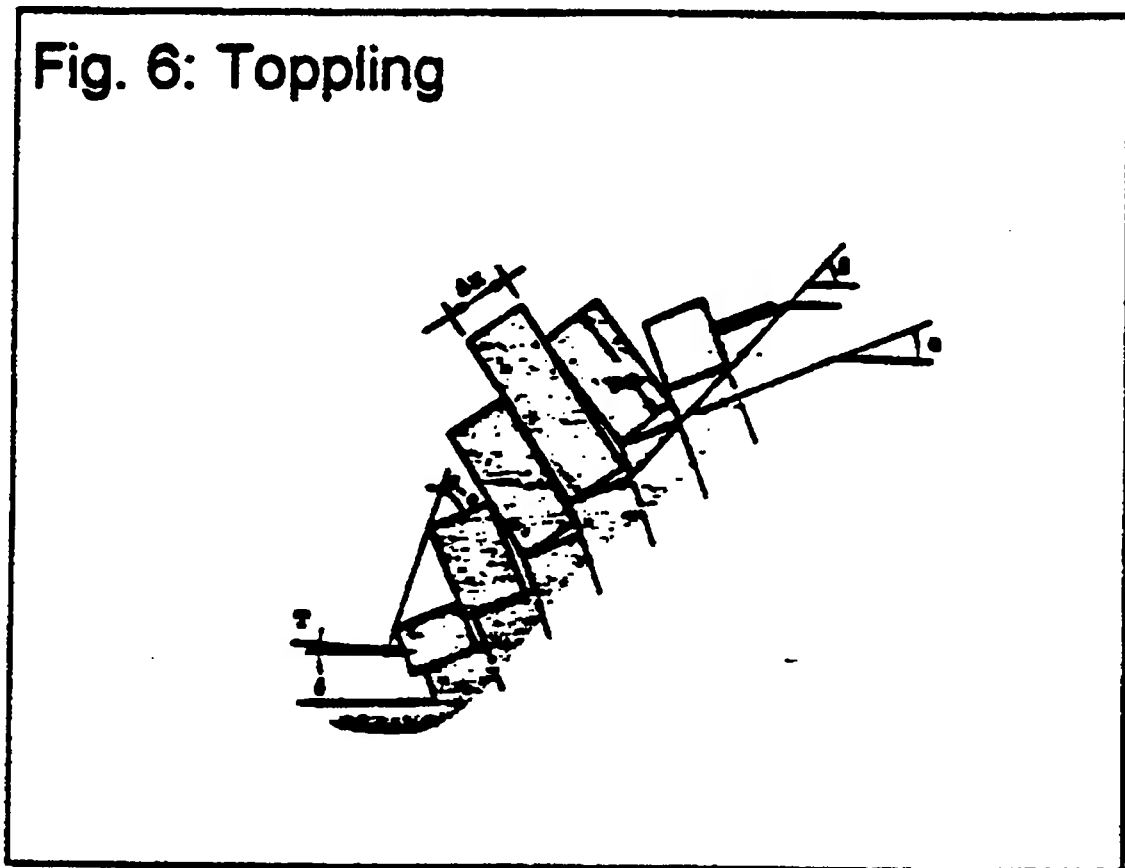
Circular failure (Fig. 5) occurs when the materials are very weak. For example in a soil slope, or when the rock mass is heavily jointed or broken, (waste rock dump). The failure will be defined by a single discontinuity surface and will tend to follow a circular failure path.

Fig. 5 **Circular Failure**



Toppling (Fig. 6) occurs when the sub-vertical layers become unsteady and fall over.

Fig. 6 Toppling



Weathering or deterioration of certain types of rock on exposure gives rise to a loosening of a rock mass and the gradual accumulation of loose materials on the surface and at the base of the slope.

3.2 Overall slope stability

An estimate of safe slope angle is required for the calculation of ore to waste ratios and for the pit layout. The only structural information, which may be available at this stage, is that which has been obtained from diamond drill cores logging and from geological mapping and structural measurements. Scant as this information may be, it does provide a basis for the estimate of potential slope problems.

Slope height versus slope angle

In Figure 7 (after Hoek and Bray, 1981), the slope heights and corresponding slope angles in materials classified as hard rock has been plotted. This plot shows that the highest and steepest slopes, which have been successfully excavated, fall along a clear line shown in dashes. This line gives a useful, practical guide to the highest and steepest slopes, which can be contemplated for normal open pit mine planning. **A steeper slope could only be justified if a very comprehensive stability study shows that there is no risk of indicating a massive slope failure.**

Fig. 7 Slope height versus slope angle (Hoek and Bray, 1981)

